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James Clerk Maxwell 150 years on

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This paper is the preface to a special Issue of *Phil. Trans. R. Soc. A* reporting selected proceedings of the international conference marking the 150th anniversary of James Clerk Maxwell's professorial debut at Marischal College, Aberdeen. Following an introduction to Marischal College, a brief historical note summarizes Maxwell's life prior to his entering the college as professor of natural philosophy. The preface provides a short summary of the event and overviews the contributed papers devoted to subjects covering a wide range of Maxwell's research interests and their modern developments. The mixture of review and research papers reflects both the fundamental importance and the diverse applicability of Maxwell's works in electromagnetics, colour science, dynamics and kinetics. Acknowledgements are given to the individuals and bodies who made the conference the success that it was.

Keywords: James Clerk Maxwell; history of science; Saturn's rings; colour science; electromagnetics; relativity

This Issue reports selected proceedings of a conference held in September 2006 to mark the 150th anniversary of James Clerk Maxwell's first professorial appointment. It was an appropriate occasion both to look back on the man himself and to take a snapshot of some current developments in the fields to which he made seminal contributions. We believe it was C. A. Coulson who said that there was scarcely a subject Maxwell looked at, and he looked at many, that his insight did not change out of recognition. The test of time is a test that tarnishes many reputations. Maxwell's reputation has not only withstood that test but he stands higher in repute now than he did in his own, comparatively short, lifetime. Maxwell's tutor at Cambridge, the outstanding William Hopkins, once remarked to a friend that 'it appears impossible for Maxwell to think incorrectly on physical subjects'. Although it was a passing comment on the young Maxwell's prowess with his coursework, it is an

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One contribution of 20 to a Theme Issue 'James Clerk Maxwell 150 years on'.

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assessment that posterity echoes when looking back on the work of his entire career. There is no question that James Clerk Maxwell deserves recognition 150 years on.

Any university that was lucky enough to have Maxwell on its staff would surely rate him as one of the outstanding professors in its entire history. Marischal College, Aberdeen, was where Maxwell took up his first post. Scotland was no academic backwater and for centuries the Scots had wryly observed that they had five universities while England had only two. Marischal College was a fully fledged university founded in the late 1500s as a progressive alternative to the well-established but by then reactionary King's College, Aberdeen. Marischal College lived up to the progressive aspirations of its founder, the 5th Earl Marischal, particularly in the sciences. Its mission statement, had it had one in those days, was to provide a first-rate education for as many as could benefit from its courses. Scholarship and research were not obligations for the staff, although staff of the calibre expected would be independent and talented individuals capable of such pursuits. As it happened, Maxwell arrived in 1856 at an inauspicious time for the college, as its life as an independent university was to have only 4 years to run. A merger with the neighbouring King's College that had been promoted in one way or another for well over half a century was finally forced through while Maxwell was in post. The University of Aberdeen was the result. The twin historic pillars on which the University of Aberdeen rests tend to be overlooked these days. Staff who were formerly in both the universities are seen as part of the history of the University of Aberdeen.

It was entirely appropriate, then, that the University of Aberdeen should mark Maxwell's professorial debut. The Marischal College building that Maxwell came to is still standing, ornamented by later benefactors to the extent that it is credited as being the second largest granite building in the world. Figure 1 shows the bust of James Clerk Maxwell displayed at the college. Sadly, it is now used very little for teaching but an appropriate venue for the reception and opening day's technical talks was provided by the Marischal Museum, which is the university's main public access museum. Participants could sample the atmosphere of the quadrangle that Maxwell crossed for the 4 years when he was a professor at the college, albeit now occupied with cars rather than gowned staff and students. In the biographies of Maxwell, not a lot is said about Marischal College itself. This omission is addressed by one of the talks that was given on the second afternoon of the meeting at a session held in the King's College campus that was open to the general public. This session proved highly successful, attracting an audience of approximately 200 to hear talks on Maxwell and his achievements. It is not uncommon to hear it said that the Scots have forgotten Maxwell. Many have not and it was notable that, in a short BBC TV series in early 2007 to find the 10 most significant events in Scottish history, a panel of historical 'experts' did not rate Maxwell's contributions at all but the general public overturned that opinion and voted him into the top 10. Prior to the conference, in the summer of 2006, events in various centres in Scotland celebrated the 175th anniversary of Maxwell's birth.

Several authors of the papers in this Issue comment on aspects of Maxwell's life. The briefest summary of his days before coming to Aberdeen is this. James Clerk Maxwell was born on 13 June 1831 at 14 India Street, Edinburgh, a house in the New Town that had been built to order by his father approximately

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Figure 1. Bust of James Clerk Maxwell in ornamental surround located in the picture gallery at Marischal College, Aberdeen, commemorating his tenure there as professor of natural philosophy. The posthumous bronze was commissioned from the sculptor Charles d'Orville Pilkington Jackson to mark the centenary of Clerk Maxwell's Marischal College appointment. It was executed after a detailed study of all available images of Maxwell by the artist. Photo courtesy of Dr John S. Reid.

21 years earlier. As an only child in a time of large families, James received more attention from his parents than was usual. His mother tragically died from cancer when he was eight-and-a-half years old, leaving his father, who was already very close to James, to see to his education and upbringing. John Clerk Maxwell was an inspirational man—a lawyer with a strong scientific and technical interest: idiosyncratic, enquiring, versatile, energetic, compassionate, an independent character who educated young James by example more diversely than any formal school could have achieved. John Clerk Maxwell had inherited the residue of the Middlebie estate, approximately 700 ha, in Kirkcudbrightshire, some 7 miles from Castle Douglas. The estate was poor and Maxwell senior built the laird's

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house, known as Glenlair. Young Maxwell spent his youth partly on the estate and partly with his father's sister (Mrs Wedderburn), who lived round the corner from India Street in Edinburgh New Town at 31 Heriot Row.

His father did not neglect James's formal education. From 1841 to 1847 he went to the comparatively newly established Edinburgh Academy; from 1847 to 1850 to Edinburgh University; from 1850 to 1854 to the University of Cambridge as an undergraduate, initially to Peterhouse but before the first year was out to Trinity. After graduating and staying on as a private tutor, he was awarded a Fellowship at Trinity College in 1855. In early 1856, James Clerk Maxwell, a young Fellow of Trinity, applied for the post of professor of natural philosophy at Marischal College, Aberdeen. His application was successful. His career path via Cambridge was not unlike that of William Thomson, who a decade earlier had succeeded to the chair of natural philosophy at the University of Glasgow also as a young man in his twenties. Indeed, Maxwell's close contemporary and lifelong friend Peter Guthrie Tait went from the Edinburgh Academy to undergraduate life at Cambridge and, via Belfast, in his late twenties to another Scottish chair of natural philosophy, in Edinburgh. They may all have been appointed young, but Tait, Thomson and Maxwell raised Scottish natural philosophy to the top rank of international prestige. Of the trio, it is Maxwell's contributions over his lifetime that to this day seem truly awesome.

Maxwell's interests and influence were so diverse that no short meeting could cover them all. Review papers in the meeting were aimed at a broad audience, introducing a field to the non-specialist from the background of our modern understanding and outlining the role that Maxwell's work plays in underpinning the subject. Other papers described specific advances in fields that have developed from Maxwell's work, particularly in the field of electromagnetism. The breadth of coverage stimulated a cross-fertilization of ideas and broadened everyone's appreciation of the enormous influence of Maxwell's work. Another meeting could, with equal validity, have covered quite a different set of subjects.

The opening paper by Reid (2008) on Maxwell at Marischal College contains new and valuable information and insights on Maxwell's teaching that have not appeared in any of Maxwell's biographies. Longair (2008) follows this with a review of Maxwell's contribution to colour science, an area of enormous relevance to twenty-first century life but one in which Maxwell's fundamental work is not cited as often as is deserved, in spite of the well-named Maxwell colour triangle. The colour triangle represents a geometrical organization of additive colour mixing but behind the geometry Maxwell introduced the modern quantitative representation of colours in a three-dimensional vector space. Continuing the overview theme of the opening papers, Garber (2008) explores how Maxwell was better known for his work on Saturn's rings and molecular science in the nineteenth century than for his electromagnetism. Maxwell's detailed mathematical discussion of the stability of Saturn's rings remains one of the masterpieces of nineteenth century mathematical physics but the subject has blossomed today into the broader subject of the stability and evolution of planetary discs and accretion discs, as Ogilvie (2008) demonstrates with great clarity.

These first four papers cover four very different aspects of Maxwell's work. None were simply passing fancies but were topics that Maxwell considered in depth and at length. Fedele (2008) further illustrates the impact of Maxwell's work on Saturn's rings on modern stability analysis of large systems of

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interacting particles. He expounds on the coherent instabilities of charged particle beams in high-energy accelerators that echo the gravitational analogue investigated by Maxwell.

These contributions are followed by papers exploring the influence of Maxwell's now celebrated electromagnetic theory from solar-scale phenomena through everyday scales down to optical dimensions and below, across a wide range of disciplines from fundamental physics to engineering sciences. There is a particular emphasis on the current interests in high-field applications.

The paper by Harrison (2008) provides a refreshing review of the recent observations of the solar atmosphere using instruments on the SOHO and TRACE satellites. A wide variety of phenomena related to the Sun's magnetic activity are revealed and discussed. The key explanatory physics embodied in Maxwell's equations is well brought out and the paper makes an ideal introduction for undergraduates and postgraduates entering this field.

Bingham (2008) presents a novel view of photon and electron acceleration, showing how Maxwell's work underpins what may become a new generation of miniaturized high-energy accelerators. This paper is a development of the author's earlier works on particle acceleration by laser wake-field plasma waves.

The paper by Shukla & Eliasson (2008) contains a combination of new analytical and numerical results on relativistic electron holes within which intense laser light is trapped. Their computer simulations exhibit fascinating stability and dynamics of the coupled electron hole and electromagnetic wave envelopes.

Mendonça (2008) presents an overview of the wave–particle dualism of electromagnetic radiation. Several complementary examples are provided, ranging from plasma physics to photonics and nonlinear physics. The author offers insights into Maxwell's equations linking the exact electromagnetic wave theory to geometric optics, with the properties of light described by different levels of interpretation, covering the wave aspects to corpuscular ones.

Vorgul (2008) presents new results on Maxwell's equations in non-stationary media. The problem is topical since properties of many radiative media of recent interest often vary with time. She studies in particular the splash-like change of medium parameters used to model any discharge phenomena, growing plasma and charge injection.

Maxwell's equations are the basis for all optical holography. Sun *et al.* (2008) demonstrate how they are used in digital holography, reporting on the novel application of Maxwell's work to develop a subsea digital holographic camera (eHoloCam). The technology offers advantages of three-dimensional spatial reconstruction and the ability to record holographic videos. This paper is well illustrated and supplemented with sample images and video clips including those obtained from recent deployments of eHoloCam in the North Sea and Faeroes Channel.

A meticulous review is then given by Lowther & Freeman (2008) on the industrial application of Maxwell's electromagnetics, mainly as electrical machines, at low frequencies. Although the pre-Maxwell's laws of electromagnetism due to Ampere and Faraday are adequate for such applications, the authors emphasize the Maxwell stress equations in determining the required forces. This in turn requires modern computing power and its further advance will enhance the design of the next generation of electrical machinery.

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In recognition of Maxwell's work on kinetics and elastic solids, the following four short research papers are dedicated to some of the recent developments of these subjects, with emphasis on applied micro- and nanomechanics.

Inspired by Maxwell, Kashtalyan & Menshykova (2008) analyse in three dimensions the mechanical deformation of a functionally graded coating under mechanical loading. Comparisons are given of the stress and displacement fields in the system with and without the functional grading. The paper by Guz *et al.* (2008) is devoted to the modern field of nanotechnology. The paper draws on the similarities between the process of whiskerization of microfibres and the recent idea of bristled nanowires. A new improved method of evaluating the elastic properties of such materials is suggested as the next stage in modelling these materials and hence being able to design applications for bristled nanowires.

Menshykov *et al.* (2008) study the validation of a method for solving elastodynamics problems for cracked solids. Crack defects appear in real-life materials during their fabrication or use, considerably decreasing their strength and useful lifetime. Crack analysis is notoriously difficult and the authors show how to obtain particular results for the problem of an interface penny-shaped crack between two dissimilar elastic half-spaces under harmonic loading. Winiarski & Guz (2008) address the theory behind another issue of cracks in real materials, namely the fracture mechanics of composites compressed along layers with interfacial cracks. The statement of the problem is based on the model of a piecewise-homogeneous medium. The layers are modelled by a transversally isotropic material of a matrix reinforced by parallel fibres. Results are obtained for the typical dispositions of cracks. It was found that the interacting crack faces, the crack length and the mutual position of cracks influence the critical strain in the composite.

Our three final papers are devoted to the topics related to special and general relativity. Here, we look again at Maxwell's electromagnetic theory, this time in terms of its fundamental aspects and implications. Einstein praised Maxwell's work as 'the most profound and the most fruitful that physics has experienced since the time of Newton'. The paper by Hall (2008) provides a clear survey of the prior developments of electricity and magnetism and their subsequent unification into a single theory by Maxwell. Based on this theory, Hall further explains how Einstein derived special relativity, a foundation of modern physics.

Einstein's derivation invokes explicitly the constancy of the speed of light, a consequence of Maxwell's electromagnetics and the invariance of physical laws in all inertial frames. The paper by Dunstan (2008) provides an alternative derivation of special relativity. Starting from a different combination of principles from Ampere, Faraday, Maxwell and Newton, the author argues that special relativity can be derived.

Another remarkable property of Maxwell's theory is that it is the earliest physical theory to have a gauge symmetry. This property is crucial in the successful quantization of electrodynamics. Similar but higher order gauge symmetries have enabled the quantization of other fundamental field theories of Yang–Mills-type describing nuclear forces. This holds out the hope that gravity might be quantized if general relativity is also given a gauge structure. The paper by Wang (2008) addresses such a problem and proposes a new gauge structure for canonical gravity.

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Maxwell is often presented as the consummate mathematical physicist but he had a strong practical turn of both hand and mind. Indeed his final Chair, at Cambridge, was that of professor of experimental physics. Maxwell was a genuinely modest man. He would have been astonished and surely delighted had he known that, 150 years on from his first professorial post, his insights and his inspiration are appreciated worldwide by the gamut of scientists working on the most fundamental of physics to the most applied engineering.

Maxwell was an active member of the Royal Society for much of his career and the Royal Society recognized his importance early on. Indeed, while still at Marischal College, Maxwell was invited by the Council of the Royal Society to be its Bakerian Lecturer. Maxwell himself had to point out to the President, G. G. Stokes, that he had not yet been elected a Fellow and the invitation would have to be put on ice. That omission was soon rectified and Maxwell eventually delivered the Bakerian lecture in 1866 *On the viscosity or internal friction of air and other gases*, a subject whose theoretical and experimental foundations he had laid while at Marischal College. We are very grateful to the Royal Society for supporting the publication of these transactions.

We are pleased to acknowledge the financial support and facilities of the University of Aberdeen, without which this conference would not have taken place, and additional financial support from CCLRC (now STFC), the Centre for Fundamental Physics and from the Institute of Physics. We are also grateful to the Scottish Universities Physics Alliance (SUPA) and to the James Clerk Maxwell Foundation (http://www.clerkmaxwellfoundation.org/), which is based in the building where Maxwell was born, for promoting the meeting. We would like to draw attention to the Maxwell at Glenlair Trust (http://www.glenlair.org.uk/), whose aim is to preserve Maxwell's family seat at Glenlair.

It was an honour that the meeting itself was opened by Prof. Ian Halliday, President of the European Science Foundation and Chief Executive of SUPA, and attendees were welcomed by Prof. Corrie Imrie, Head of the School of Engineering and Physical Sciences at the University of Aberdeen. We are also very grateful to the invited speakers who came from Britain, Europe and North America to talk on a wide range of developments in topics that would surely have proved at once recognizable and fascinating to Maxwell himself. We are grateful to the meeting chairs from Aberdeen who included Prof. Marian Wiercigroch, Prof. John Watson, Dr Geoff Dunn and Prof. Graham Hall. Prof. Albert Rodger, Head of the College of Physical Science at the University of Aberdeen, opened the public session that was chaired by Prof. Michael Thompson and Michael Sandford (RAL). We are grateful to Prof. Francis Everitt (Stanford University), Dr Alan Fenwick (QinetiQ) and Prof. Celso Grebogi (Aberdeen) for helpful suggestions. On behalf of all the authors represented in these proceedings, we would like to thank the referees of the papers for their careful scrutiny and useful suggestions. Finally, we would like to record that the conference was honoured to have the blessing of Maxwell's closest living relatives, Sir Robert Maxwell Clerk, Ms Honor Clerk and Mr Keir Wedderburn-Maxwell, descendants of his uncle and aunt on his father's side, for Maxwell had no siblings and no children of his own.

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Appendix

The full list of invited speakers and their topics is shown below. Contributions shown in italics are published in this issue. In addition, seven papers (Dunstan 2008; Guz *et al.* 2008; Kashtalyan & Menshykova 2008; Menshykov *et al.* 2008; Sun *et al.* 2008; Vorgul 2008; Winiarski & Guz 2008) are published that were presented in the form of posters.

Photons and future particle accelerators	*Robert Bingham*
Maxwell and the classical wave-particle dualism	*Tito Mendonça*
The magnetic Sun	*Richard Harrison*
From the Maxwell theory of Saturn's rings to the negative-mass instability	*Renato Fedele*
Dynamics of astrophysical discs	*Gordon Ogilvie*
How Maxwell's equations are used on a daily basis in down-hole logging for oil and gas exploration	Barbara Anderson (Schlumberger Ltd)
An example of Prof. Maxwell's work relating to electromagnetics concerning present day water pipeline leak location solutions	Anthony Bond & Ranald Macdonald (WRc plc)
Using electromagnetic waves to heat fusion plasmas	Alan Cairns (University of St Andrews)
Localization of intense electromagnetic waves in plasmas	*Padma Shukla*
Coherent electromagnetic wave generation by relativistic electrons	Alan Phelps (University of Strathclyde)
Maxwell's equations—solution methods, past, present and future	*David Lowther*
Perspectives on the relevance of gravitation for the covariant description of electromagnetically polarizable media	Robin Tucker (Lancaster University)
Gauge formulation of general relativity using conformal and spin symmetries	*Charles Wang*
James Clerk Maxwell at Aberdeen	*John Reid*
Maxwell and the science of colour	*Malcolm Longair*
Maxwell on subjects great and small: Saturn's rings and molecular science	*Elizabeth Garber*
Maxwell's electromagnetic theory and the special theory of relativity	*Graham Hall*

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